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RESEARCH PAPER

Temperature dependence of carbon mineralization and nitrous oxide emission in a temperate forest ecosystem

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Abstract: The measurement of CO_2 and N_2O efflux from forest soils is of great importance in evaluating the role of forests as sequestering agents of atmospheric CO_2 and nitrogen. To quantify the effect of site on temperature dependence of net C-mineralization and N_2O-N emissions, three adjacent forest floors under beech, Norway spruce and mixed species stands were investigated at Solling forest, Germany, by an incubation experiment for three months. The investigated net C-mineralization and N_2O-N emissions from all forest floors exhibited an exponential increase with respect to temperature elevation. The temperature coefficient function (Q_{10} value), was fitted to flux rates to describe the temperature sensitivity of forest floors on temperature in the range of 1–20ºC. Comparing the fitted curves for temperature sensitivity of the forest floors in relation to net carbon mineralization and nitrous oxide emission rates revealed a strong positive correlation across all sites. For the whole data set of all stands, a Q_{10} value of 1.73–2.10 for net C-mineralization and 2.81–3.58 for N_2O-N emissions per measured unit was found to describe the temperature dependency of net C-mineralization and N_2O-N efflux at experimental site. The absence of clear differences between beech and spruce in mono and mixed species cultures on temperature dependencies of net C-mineralization and N_2O-N emission rates indicated that the flux rates were not affected by species-specific differences of litter quality.

Keywords: beech; spruce; net C-mineralization; nitrous oxide emission; temperature; temperature sensitivity index (Q_{10})

Introduction

It has been hypothesized that increasing CO_2 concentrations in the atmosphere may increase global temperature, which stimulate the flux of carbon dioxide from soils causing a positive feed back effect on the atmospheric CO_2 (Jenkinson et al. 1991; Schimel et al. 1994; Kirschbaum 1995). In fact the ability of forest soils to sequester carbon through forest floor is of particular interest since forest ecosystems potentially represent an increasing sink for carbon as atmospheric CO_2 is increased and photosynthesis stimulated (Raich et al. 1992). Conversely, temperature elevation resulting from increasing greenhouse gases in the atmosphere may counteract this increase in carbon accumulation in soils by stimulating the mineralization rate of organic carbon pools in forest soils by heterotrophic microorganisms (Jenkinson et al. 1991). Therefore, changes in soil carbon storage abilities may in turn affect atmospheric CO_2 concentration during the next decades in different ways depending on local climate and site characteristics (Kirschbaum 1995). The strong correlation between soil respiration and temperature has been quantified for many soils under different conditions (Raich et al. 1992; Lloyd et al. 1994; Houghton et al. 1998; Kirschbaum 1995, 2000; Schlesinger et al. 2000). In many decomposition studies, the temperature response function, Q_{10} value, is used to describe the effects of elevating temperature due to climate change on the mineralization of soil carbon pools and dependence of decomposition on temperature (Jenkinson et al. 1991; Anderson 1992; Chen et al. 2000; Fang et al. 2001). Beside carbon dioxide, nitrous oxide (N_2O) as an atmospheric trace gas plays an important role in atmospheric chemistry as well as in global warming (e.g. Ramanathan et al. 1985; Cicerone 1987). As the biogeochemical cycling of nitrogen in soils depends strongly on temperature and precipitation, the potential increase in N_2O release from the forest floor caused by elevating temperatures may have a positive feed back effect on the atmospheric N_2O as a result of depletion of higher nitrous oxide emissions. The present study aimed to characterize the effects of temperature on net C-mineralization and N_2O-N emission rates in the forest floors of the three adjacent stands at Solling forest, Germany. It is of great interest to find the role of temperature elevation on biochemical processes indexed by Q_{10} value of the flux rates of trace gases with respect to different substrate quality of the forest floors.

Materials and methods

Site description

The study site is located at the Solling forest about 70 to 80 km southward Hannover, Lower Saxony, Germany (51°47′N and

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9°37′E) on slightly inclined (2–4°) slopes. The area is situated at 500 m elevation a.s.l. with a mean annual air temperature of 6.5°C and an annual precipitation of 1 050 mm. The temperature ranges from an average of 14°C in July to -2°C in January. The dominant soil types are podsolic, slightly pseudogleyic Dystric Cambisol (FAO) developed on triassic sandstone covered by a layer of loess with a thickness varying from 0.2 to 2 m (average 80 cm), (Tiktak et al. 1995). Soil texture is dominated by silty loam. Morphological humus forms are typical moder. Three adjacent stands (area of each ≈ 400 m^2) were chosen for the study: a mature (100–120 years old) Norway spruce (*Picea abies* L. karst.) stand partly covered by grass, a 100 to 120-yr-old beech (*Fagus sylvatica* L.) stand and a mixed spruce-beech stand covered by 100 to 120-yr-old trees.

Soil sampling and experimental design

Undisturbed forest floor samples (n = 120) were taken from each stand by using a stainless steal auger, placed into an incubation vessel (8.4 cm at diameter, 14 cm in height). Soil cores were sampled randomly and were stored at 4°C for a few days until incubation. Samples were incubated at 1, 5, 10, 15 and 20 °C with six replications from each stand at each temperature for three months. The moisture content of the samples was controlled by continuous weighing over the incubation period.

Forest floor chemical analyses and calculations

The CO_2 and N_2O emission rates from the soil cores were measured once a week throughout the incubation in airtight vessels. CO_2 and N_2O fluxes were determined by means of head space enrichment at 0, 10, and 20 minutes, using the slope of the temporal change in gas concentration within the headspace. Gas samples were analyzed by injection of gas sample into the port of a gas chromatograph (GC 14 A, Shimadzu, Duisburg, Germany) equipped with two detectors, a flame ionization detector (FID), and an electron capture detector (ECD), (Loftfield et al. 1997). The CO_2 and N_2O fluxes were calculated using linear regression of the change in gas concentration, based on the following equations:

$$F = k_{CO_2} \frac{273}{T} \times \frac{P}{101} \times \frac{V}{A} \times \frac{\Delta C}{\Delta t} \quad (1)$$

$$F = k_{NO_2} \frac{273}{T} \times \frac{P}{101} \times \frac{V}{A} \times \frac{\Delta C}{\Delta t} \quad (2)$$

where, F is the flux rate of CO_2 ($mg \cdot m^{-2} \cdot h^{-1}$) or N_2O ($\mu g \cdot m^{-2} \cdot h^{-1}$), k_{CO2} (0.536 $\mu g \cdot \mu L^{-1}$) and k_{N2O} (1.25 $\mu g \cdot \mu L^{-1}$) are both unit conversion factors for calculating CO_2 and N_2O flux rates. T is the air temperature (°K). P is the atmospheric pressure (kPa). V is the air volume of the headspace gas above the samples (L). A is the area of soil samples (m^2) and $\Delta C/\Delta t$ is the rate of change in concentration of CO_2 and N_2O, within the headspace ($\mu L \cdot L^{-1} \cdot h^{-1}$).

An exponential function equation was used to calculate the temperature effects on soil CO_2-C and N_2O-N fluxes by a fitting procedure:

$$F_{lux} = b_0 \times e^{(b_1 \times T)} \quad (3)$$

where, F_{lux} is the measured CO_2-C or N_2O-N emissions. T is the soil temperature. The parameter b_0 (for which no biological meaning is given) represents the flux rate at 0°C and b_1 is the response of the flux to temperature (Davidson et al. 1998).

The temperature sensitivity function (Q_{10}) was used to show temperature sensitivities of a complex of biochemical processes in soil, calculated as:

$$Q_{10} = e^{(10\, b1)} \quad (4)$$

The total C and N content of the forest floor were analyzed by dry combustion with a CN- auto analyzer (Vario, Elementar Analysensysteme, Hanau, Germany). Soil pH was measured with a digital pH-meter (WTW GmbH Wesl-Germany) in water and 1 $mol \cdot L^{-1}$ of KCl (Table1).

Statistics

Analyses of variance (ANOVA) were tested by Mann-Whitney U-Test at $p<0.05$ level, performed by the program Statistica version 6.0.

Results and discussion

Soil chemical characteristics

The thickness and mass of the forest floors increased slightly from beech over mixed species to spruce forests, but they are not significantly different between the stands ($p<0.05$). Site variation effects on chemical characteristics of the forest floors were also negligible ($p<0.05$) as shown in Table 1. The $pH_{(KCl)}$ of the forest floors were very low, ranged from 2.91 to 3.08. The concentrations of organic carbon ranged from 277.7 to 298 $g \cdot kg^{-1}$ were not significantly different among species (Table 1). Total nitrogen concentrations of all stands were in the range of 13.0–14.2 $g \cdot kg^{-1}$, indicating no significant differences between species composition of forest floors ($p<0.05$). The total carbon and nitrogen stores measured in our study were in the range of values observed from pervious studies at beech and spruce sites in Solling (Tiktak et al. 1995, Meesenburg et al. 1999). The values of C/N ratio at spruce (23.0) and mixed species cultures (21.3) were slightly higher than the values obtained at beech stand (19.6). The narrower C/N ratio at beech stand indicated higher N immobilization from more nitrogen deposition by N-enriched litter and lower accumulation rates for carbon than for nitrogen at beech stand.

Temperature dependence of net C-mineralization

The rates of net C-mineralization increased exponentially (R^2=0.92–0.99) with increase of temperature during twelve weeks incubation period at the three stands (Table 2, 4). The values of net C mineralization at spruce stand was slightly higher than those of the net C-mineralized at beech and mixed species stands, however except lower temperatures the fluxes were not

significantly different between the stands (Table 3). To indicate temperature dependence of forest floor net C-mineralization, an exponential regression equation (Davidson et al. 1998) was used along the temperature increase. Comparing the fitted curves of net C-mineralization between the three stands indicated that the effect of mixed species on carbon losses ranged from pure beech to pure spruce (Fig. 1). The flux rate of CO_2-C at mean annual air temperature of the study area was in magnitude consistent with mean annual soil respiration rates observed in chamber experiments by Brumme 1995 and Borken et al. 2002 at Solling (Table 4). As a result of insignificant differences between the stands the mean net carbon mineralization of experimental site along temperature elevation was calculated and shown in Fig. 2.

Table 1. Mean forest floor characteristics of each stand

Stand	Depth^{ns} (cm)	Mass^{ns} (t·ha^{-1})	Moisture^{ns} (%)	pH^{ns} (KCl)	pH^{ns} (H_2O)	$C_{org}{}^{ns}$ (g·kg^{-1})	$N_t{}^{ns}$(g·kg^{-1})	C/N^{ns}
beech	5.03a	49.0a	59.5a	3.08a	3.81a	277.7a	14.2a	19.6a
	(0.2)	(10.7)	(2.42)	(0.14)	(0.18)	(35.7)	(1.64)	(1.36)
spruce	5.77a	57.5a	61.0a	2.91a	3.62a	298.0a	13.0a	23.0 a
	(0.3)	(21.4)	(8.74)	(0.12)	(0.19)	(30.5)	(1.56)	(1.93)
mixed	5.41a	53.2a	59.4a	2.97a	3.66a	289.9a	13.6a	21.3 a
	(0.3)	(18.4)	(9.41)	(0.16)	(0.12)	(34.0)	(1.66)	(1.62)

Notes: Standard deviation is given in parentheses. Values with different superscript letters are significantly different from one another, (ns= not significant, $p<0.05$).

Table 2. Mean net C mineralization in the forest floors of the three stands along temperature increase over the incubation period

NCM	Stand	Temperature (°C) 1	5	10	15	20
per unit-area	beech	0.25 (0.10)	0.47 (0.04)	0.54 (0.15)	0.77 (0.05)	0.99 (0.22)
(g·m^{-2}·d^{-1})	spruce	0.45 (0.10)	0.60 (0.22)	0.67 (0.20)	0.95 (0.31)	1.27 (0.33)
	mixed	0.26 (0.07)	0.48 (0.09)	0.56 (0.10)	0.67 (0.12)	0.87 (0.15)
per unit-mass	beech	0.04 (0.02)	0.09 (0.02)	0.12 (0.03)	0.19 (0.04)	0.22 (0.07)
(g·kg^{-1}·d^{-1})	spruce	0.07 (0.02)	0.09 (0.02)	0.12 (0.04)	0.21 (0.05)	0.29 (0.07)
	mixed	0.04 (0.01)	0.06 (0.02)	0.14 (0.05)	0.17 (0.04)	0.22 (0.06)
per unit-C_{org}	beech	0.12 (0.04)	0.24 (0.04)	0.31 (0.06)	0.48 (0.10)	0.60 (0.18)
(g·kg^{-1}·d^{-1})	spruce	0.20 (0.07)	0.24 (0.04)	0.30 (0.11)	0.54 (0.11)	0.78 (0.19)
	mixed	0.13 (0.04)	0.16 (0.04)	0.38 (0.12)	0.46 (0.10)	0.62 (0.15)

Notes: Standard deviation is given in parentheses.

Table 3. Results of statistical tests on mean NCM (left) and N_2O-N flux (right) between the stands at different incubation temperatures per measured unit

CO_2-C flux	Stand	1ºC		5ºC		10ºC		15ºC		20ºC	
	beech/spruce	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
per unit-area	spruce/mixed	*	ns	ns	*	ns	ns	ns	ns	*	ns
	beech/mixed	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	beech/spruce	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
per unit-mass	spruce/mixed	*	ns	*	*	ns	ns	ns	ns	ns	ns
	beech/mixed	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
	beech/spruce	ns	_	ns	_	ns	_	ns	_	ns	_
per unit-C_{org}	spruce/mixed	ns	_	*	_	ns	_	ns	_	ns	_
	beech/mixed	ns	_	*	_	ns	_	ns	_	ns	_
	beech/spruce	_	ns	_	ns	_	ns	_	ns	_	ns
per unit-N_t	spruce/mixed	_	*	_	*	_	ns	_	ns	_	ns
	beech/mixed	_	ns	_	ns	_	ns	_	ns	_	ns

Notes: Mann-Whitney (U-Test), [(ns): not significant, (*): significant, $p<0.05$].

The Q_{10} value as index of temperature sensitivity of CO_2-C fluxes ranged from 1.64 to 2.26 per measured unit, revealed no significant differences regarding net carbon mineralization between the stands (Table 4). In agreement with our results, Chen et al. (2000) concluded that similar temperature responses of net C-mineralization between the stands at the same climatic zone may provide similar conditions for decomposer groups so that the relative activities of decomposers can be influenced more by abiotic factors such as temperature than biotic factors such as species and decay class in similar moisture content of the forest floors. In order to fit a model of carbon mineralization as a function of temperature elevation at the study area, the mean Q_{10} value of the experimental site was calculated and ranged from 1.73 to 2.10 per measured unit (R^2 = 0.98–0.99), (Table 5). The Q_{10} values for microbial respiration in present study are in the range of Q_{10} values from laboratory incubation studies in temperate forests. For instance, Winkler et al. (1996) obtained Q_{10} value of only 1.7–1.9 over a temperature range of 4–28 ºC for the A-horizon of a forest soil and Boone et al. (1998) calculated a Q_{10} of 2.5 for forest soil respiration excluding roots.

Borken et al. (2002) measured mean Q_{10} values for the temperature range from 5 to 15 ºC from 1.87 at 0 cm to 3.46 at 10 cm depth in European beech, Norway spruce and Scots pine forests.

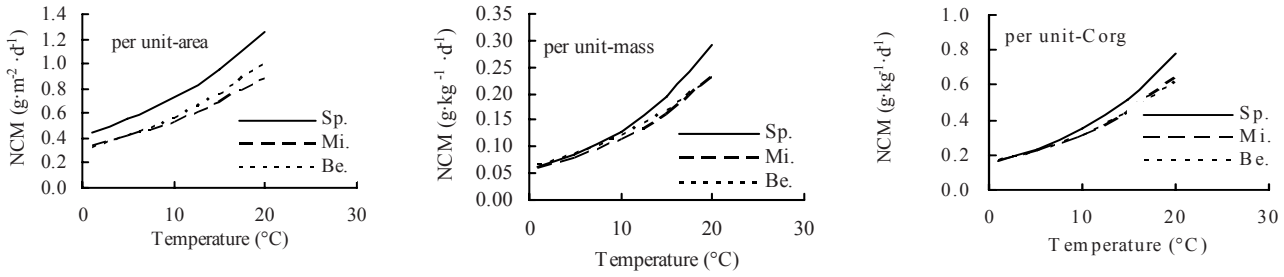

Fig. 1 Relationships between net C-mineralization per measured unit and temperature (ºC)

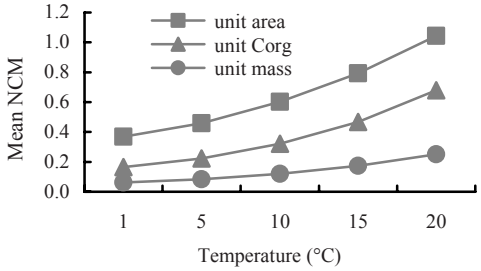

Fig. 2 Relationships between mean net C-mineralization of the three stands per unit area ($g \cdot m^{-2} \cdot d^{-1}$), mass ($g \cdot kg^{-1} \cdot d^{-1}$), and C_{org} ($g \cdot kg^{-1} \cdot d^{-1}$) and temperature (ºC)

Table 4. Parameters of the Q_{10} regressions fitted on the NCM data and the CO_2-C flux at mean annual air temperature at each stand

CO_2-C flux	Stand	b_0	b_1	R^2	Q_{10}	CO_2-C flux at 6.5ºC
per unit-area ($g \cdot m^{-2} \cdot d^{-1}$)	beech	0.301	0.060	0.97	1.83	0.445
	spruce	0.422	0.055	0.99	1.73	0.601
	mixed	0.323	0.050	0.95	1.64	0.447
per unit-mass ($g \cdot kg^{-1} \cdot d^{-1}$)	beech	0.061	0.066	0.95	1.94	0.094
	spruce	0.057	0.082	0.99	2.26	0.097
	mixed	0.056	0.071	0.92	2.02	0.088
per unit-C_{org} ($g \cdot kg^{-1} \cdot d^{-1}$)	beech	0.157	0.069	0.97	1.99	0.245
	spruce	0.155	0.081	0.98	2.24	0.262
	mixed	0.149	0.073	0.94	2.07	0.239

Kaetterer et al., (1998) indicated a strong temperature dependence of carbon mineralization rate with the Q_{10} value of 2 in the temperature range of 5–35ºC and Reichstein et al. 2000 measured a Q_{10} value of 2.5 by 104-day laboratory incubation at 5, 15 and 25 ºC of the organic layer in sub-alpine soils. Lloyd and Taylor (1994) argued that over a wide temperature range, microbial populations responsible for soil organic matter decomposition might change along the experiment. Hence, Q_{10} values, as indicator of temperature sensitivity, may alter due to change in biochemical reactions of decomposers concerning temperature variations. In consistent the measured initial Q_{10} value of each stand at beginning of experiment revealed higher values than the mean Q_{10} value over the incubation period (Table 5).

This implies that at beginning of incubation, the easily decomposable fraction of organic matter will be mineralized more quickly than that at the later stages of incubation time when the light fraction of substrate is nearly mineralized and respiration rates are nearly constant. Hence, the Q_{10} dynamics is a result of the changing amount of decomposable matter by different temperature treatments. According to Kirschbaum (1995) as a result of the changing amount of decomposable matter along the incubation time, inhibiting metabolites may have been accumulated at later stages of incubation, and resulted in adulterate temperature dependence of C-mineralization which caused lower values of respiration rates, while at beginning of incubation the composition of samples was still unaltered and respiration rates were high due to microbial stimulation by disturbances.

Table 5. Parameters of the Q_{10} regressions fitted on mean NCM of the three stands and mean initial Q_{10} value at beginning of the experiment and mean CO_2-C flux of the three stands at mean annual air temperature of Solling

CO_2-C flux	b_0	b_1	R^2	Q_{10}	Initial Q_{10}	CO_2-C flux at 6.5ºC
per unit-area ($g \cdot m^{-2} \cdot d^{-1}$)	0.348	0.055	0.98	1.73	2.1	0.498
per unit-mass ($g \cdot kg^{-1} \cdot d^{-1}$)	0.058	0.073	0.99	2.07	2.4	0.093
per unit-C_{org} ($g \cdot kg^{-1} \cdot d^{-1}$)	0.154	0.074	0.99	2.10	2.6	0.249

Temperature dependence of N_2O-N emissions

The rates of N_2O-N efflux over the incubation period increased exponentially with increase of temperature at the three stands (Table 6 and Fig. 3). A high correlation was found between the flux rates of N_2O-N and the elevating incubation temperature at each stand (R^2 = 0.97–1.00). As general climatic and edaphic conditions for three adjacent stands were similar, the mean N_2O-N emission at experimental site along temperature increase was estimated and shown in Fig. 4.

The emissions of N_2O-N at mean annual air temperature at each stand was in consistent with measured annual emissions of N_2O-N at Solling (Brumme and Beese 1992; Brumme et al. 1999). The Q_{10} value of N_2O-N emissions from forest floors ranged from 2.38 to 3.84 between the stands dependent on the measured unit (Table 7). In consistent with our results Sitaula and Bakken (1993) determined Q_{10} values between 1.2 and 2.7 for N_2O-N production for a spruce forest. On the basis of field

measurements at a beech site, Brumme (1995) calculated Q_{10} values for different soil water tensions of 0.9–9.8 at Solling area. The calculated Q_{10} value as index of general temperature sensitivity of the experimental site ranged from 2.81 to 3.58 per measured unit (Table 8). The exponential increase in N_2O-N emission rates along the temperature increase can be explained by the stimulation of microbial N turn over rates in the forest floors and an increase of microbial population involved in N_2O production and emission (Naegele et al. 1990; Papen et al. 1991; Nodar et al. 1992). Hence, increased availability of NH_4^+ and NO_3^- in the forest floors due to general increase in nitrification and denitrification activity of micro-organisms resulted in enhanced N_2O-N emissions. Under laboratory incubation conditions, temperature elevation increased microbial oxygen demand and due to higher oxygen consumption and activity of soil micro-organisms it resulted in increase of anaerobic conditions, which may stimulate N_2O losses by denitrification (Groffman 1991). Moreover, with increasing temperature, mineralization and nitrification are stimulated which may result in a higher nitrate concentration, increased denitrification if nitrate is a limiting factor and also increased N_2O/N_2 ratio (Weier et al. 1993). Higher rates of nitrification may also increase the losses if this process is involved in the formation of N_2O.

Table 6. Mean N_2O-N flux in the forest floors of the three stands along temperature increase over the incubation period (Standard deviation is given in parentheses)

N_2O-N flux	Stand	Temperature (°C)				
		1	5	10	15	20
per unit-area	beech	0.06 (0.03)	0.11 (0.07)	0.12 (0.04)	0.29 (0.13)	0.50 (0.20)
($mg \cdot m^{-2} \cdot d^{-1}$)	spruce	0.08 (0.04)	0.15 (0.08)	0.18 (0.13)	0.27 (0.23)	0.45 (0.13)
	mixed	0.05 (0.02)	0.07 (0.03)	0.08 (0.03)	0.18 (0.16)	0.29 (0.14)
per unit-mass	beech	0.01 (0.004)	0.02 (0.01)	0.03 (0.01)	0.07 (0.02)	0.12 (0.03)
($mg \cdot kg^{-1} \cdot d^{-1}$)	spruce	0.01 (0.01)	0.02 (0.01)	0.03 (0.01)	0.05 (0.03)	0.10 (0.03)
	mixed	0.01 (0.004)	0.01 (0.01)	0.02 (0.01)	0.05 (0.04)	0.07 (0.04)
per unit-N_t	beech	0.64 (0.27)	1.17 (0.70)	1.48 (0.58)	3.66 (1.15)	6.65 (1.79)
($mg \cdot kg^{-1} \cdot d^{-1}$)	spruce	0.81 (0.37)	1.44 (0.63)	1.56 (0.72)	3.20 (1.06)	6.37 (1.31)
	mixed	0.41 (0.20)	0.55 (0.32)	1.18 (0.50)	2.62 (3.17)	4.71 (2.52)

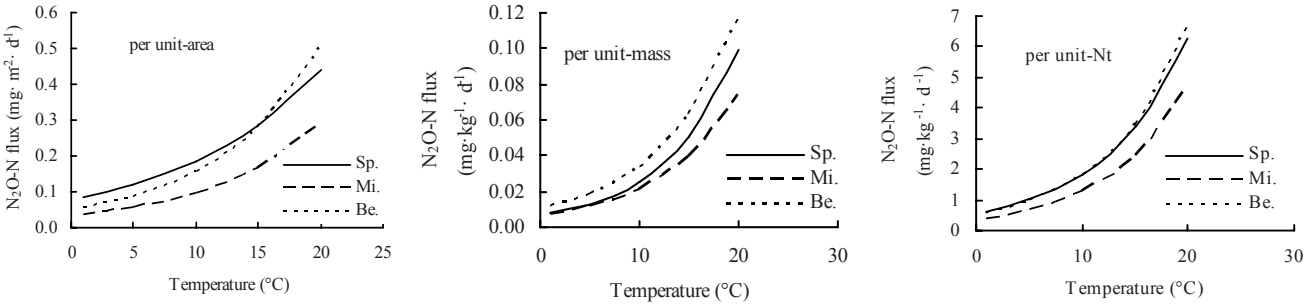

Fig. 3 Relationships between N_2O-N emission rates per measured unit and temperature (ºC)

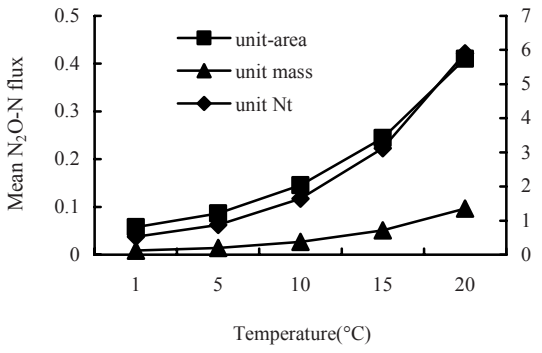

Fig. 4 Relationships between mean N_2O-N emission rate of the three stands per unit area ($mg \cdot m^{-2} \cdot d^{-1}$), mass ($mg \cdot kg^{-1} \cdot d^{-1}$) and N_{total} ($mg \cdot kg^{-1} \cdot d^{-1}$) and temperature (ºC) (Right Y axis is the emission rate per unit N_t)

Table 7. Parameters of the Q_{10} regressions fitted on the N_2O-N fluxes, and the emission of N_2O-N at mean annual air temperature at each stand

N_2O-N flux	Stand	b_0	b_1	R^2	Q_{10}	N_2O-N flux at 6.5ºC
per unit-area	beech	0.048	0.117	0.98	3.24	0.103
($mg \cdot m^{-2} \cdot d^{-1}$)	spruce	0.077	0.087	0.99	2.38	0.136
	mixed	0.032	0.109	0.98	2.99	0.066
per unit-mass	beech	0.010	0.123	0.99	3.44	0.022
($mg \cdot kg^{-1} \cdot d^{-1}$)	spruce	0.007	0.135	0.97	3.84	0.016
	mixed	0.006	0.125	0.99	3.49	0.014
per unit-N_t	beech	0.504	0.129	0.99	3.64	1.168
($mg \cdot kg^{-1} \cdot d^{-1}$)	spruce	0.546	0.122	0.98	3.39	1.207
	mixed	0.340	0.132	1.00	3.74	0.801

Notes: b_0 represents the flux rate at 0°C and b_1 is the response of the flux to temperature. Q_{10} is Temperature sensitivity index.

Table 8. Parameters of the Q_{10} regressions fitted on mean N_2O-N emissions of the three stands and mean N_2O-N flux of the three stands at mean annual air temperature of Solling

N_2O-N flux	b_0	b_1	R^2	Q_{10}	N_2O-N flux at 6.5ºC
per unit-area($mg \cdot m^{-2} \cdot d^{-1}$)	0.052	0.103	0.99	2.81	0.101
per unit-mass($mg \cdot kg^{-1} \cdot d^{-1}$)	0.008	0.127	1.00	3.56	0.017
per unit-N_t($mg \cdot kg^{-1} \cdot d^{-1}$)	0.461	0.127	0.99	3.58	1.055

Conclusions

Comparing the fitted curves with respect to temperature elevation revealed similar pattern of net C-mineralization and N_2O-N emissions between the forest floors of different substrate quality. The similar Q_{10} values between the stands suggested that the relative activities of decomposers might be influenced more by abiotic factors such as temperature than biotic factors such as microbial species and substrate quality when no significant differences was detected in chemical properties and moisture content of the forest floors. The impact of increasing temperature on N_2O-N emission rates due to higher Q_{10} values was higher than that on net C mineralization at the three stands, although the regulating factors such as moisture content were similar. It is evident from our results that under the same environmental conditions (moisture, nutrient status and soil acidity), the effect of temperature elevation on carbon mineralization and N_2O-N emission rates shows a close relationship between the rates of decomposition and trace gas fluxes. Still, reliable estimates of trace gas fluxes in forests are required to provide a better understanding of the contribution of soil CO_2 and N_2O efflux to carbon and nitrogen transformations in European forests.

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